U.S. Department of the Interior
National Park Service

Satellite-Derived Measures of Landscape Processes
DRAFT Monitoring Protocol for the Southwest Alaska Network

Protocol Narrative

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Revision History Log:

Previous Version #	*Revision Date*	*Author*	*Changes Made*	*Reason for Change*	*New Version #*

I. Background and objectives

Background and history

A primary goal of vital signs monitoring is to describe long-term trends in ecosystem properties to better understand their dynamic nature (Bennett et al., 2005). The Southwest Alaska Network (SWAN) has identified several physical and biological processes to monitor across all parks in the Network. These processes have been combined into the vital sign Landscape Processes and include the following:

1) Onset and freeze-up of ice on large freshwater bodies
2) Pattern and timing of snow cover
3) Timing of green-up and senescence in vegetation

The large size and wilderness character of the five park units that comprise the SWAN (Alagnak Wild River, Aniakchak National Monument and Preserve, Katmai National Park and Preserve, Kenai Fjords National Park, Lake Clark National Park and Preserve) limit the feasibility of broad-scale, ground-based measurements. Common themes associated with the monitoring of Landscape Processes are the need for a temporal window of days to weeks, the ability to track processes at a large spatial scale across the region, and the potential to use remotely sensed data to interpret and integrate these processes.

The primary tool to monitor these landscape processes will be multispectral satellite data acquired by the Moderate Resolution Imaging Spectroradiometer (MODIS). Terra MODIS and Aqua MODIS view the entire Earth's surface every 1 to 2 days, continuously acquiring data in 36 spectral bands at a spatial resolution of 250, 500, and 1000 m. High resolution (15-90m) ancillary data provided by the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) will be available as acquired. ASTER images received to date have already been processed and provided by the USGS Center for Earth Resources Observation and Science (EROS). As such, this protocol does not address processing or analysis of ASTER data.

Images derived from MODIS data can be analyzed manually or with algorithms to provide information about the landscape processes discussed above. Initial protocol development has been accomplished through an Interagency Agreement (IA) with USGS EROS. This protocol documents applications for MODIS data that have been developed for the SWAN.

Rationale for monitoring landscape processes

The SWAN Region occupies an area between 57° and 61° N where coastal-temperate and boreal systems merge. Low annual temperature flux, mean annual temperatures ≥ 0 °C, and high precipitation characterize the region (Redmond et al. 2005). Tree-ring chronologies and local weather records suggest a temperature increase of roughly 2 °C since the 1980s in the Lake Clark region (Driscoll et al. 2005), in agreement with the increase in average surface temperatures reported for the northern latitudes during the past century (approximately 0.09 °C/decade; ACIA, 2005). Additional temperature increases of approximately 4-7 °C are projected over the next century in the Arctic (ACIA, 2005). Along with decreases in sea ice and land glacier extent, warming over terrestrial areas has increased the frequency of mild winter days, resulting in changes in the timing of river-ice break-ups, and the frequency and severity of ice dams, floods, and low flows (ACIA, 2005). Observations from remotely sensed data and ground measurements in arctic, subarctic and boreal systems have documented such variation in the timing of freeze-thaw events (e.g., Kimball et al. 2004a, 2004b) and lake ice formation (e.g., Duguay et al. 2003, Wynne and Lillesand 1993), and have indicated shifts in plant phenology as a result of lengthened growing seasons (e.g., Delbart et al. 2005, Beaubien and Hall-Beyer 2003).

Anticipated climate-driven changes in the SWAN include sea-level rise, greater storm intensity and frequency, altered seasonal hydrology, accelerated glacial retreat, and shorter duration of lake ice cover. Storage and release of snowpack is pivotal in regulating linkages between terrestrial and aquatic systems in the region, and appears to play an important role in determining lake ice thickness and the timing of break-up (Duguay et al. 2003). It is unlikely that discrete dates can be identified for ice formation and freeze-up, or for snowpack development and loss, as these processes appear to occur over a period of days or even weeks. A more realistic approach may include monitoring the timing and duration of these transition periods in the SWAN (e.g., for lake ice formation or snowpack development), in addition to the length of the ice- and snow-free season. As with changes in ice formation, changes in snow depth and duration may lead to significant shifts in the timing and amount of runoff, and may also strongly influence growing season dynamics and net primary productivity.

Widespread increases in indices of vegetation greenness (e.g., normalized difference vegetation index (NDVI)) and biomass in northern high latitudes (Myneni et al. 1997, 2001), as well as an earlier onset of the growing season in northern regions of North America, Asia, and Europe have been observed using satellite-derived measurements (Piao et al. 2005, Stockli and Vidale 2004, Hicke et al. 2002). Early work with Advanced Very High Resolution Radiometry (AVHRR) data included the derivation of metrics for onset of greenness, time of peak NDVI, rate of senescence, and integrated NDVI (Reed et al. 1994). More recently, MODIS vegetation index data have been used to identify transition dates within annual time series, enabling investigators to monitor vegetation dynamics at large scales without user-defined thresholds (Zhang et al. 2003). Using data collected from 1982-1998, Hicke et al. (2002) showed peak net primary productivity (NDVI) in Alaska and western Canada occurring in late spring and early summer, apparently associated with warmer early season temperatures. Likewise, earlier start-of-season and/or later end-of-season dates recorded from 1989-2003 appear to have contributed to increased growing season length in the Bristol Bay Lowlands and Kuskowim Delta, Alaska (Reed, 2006).

Understanding the interactive effects of landscape, climate and disturbance on ecological condition is integral to the preservation and protection of public lands, and to determining the appropriate management strategies to employ. Park ecosystems develop and are maintained by landscape processes related to climate, geology and hydrology that operate over a range of scales and influence the abundance and productivity of plants and animals. While natural processes are largely outside the control of natural resource managers, understanding these processes provides important ecological context for interpreting changes in park resources. For example, documenting broad-based events such as the duration of snow and ice cover is particularly important because extreme events can have immediate and long-lasting effects on ecosystems and species. Furthermore, monitoring landscape processes may support ecological forecasts that alert park managers to future issues of management concern such as the potential for floods or wildland fires.

Measurable objectives

Monitoring of landscape processes in the SWAN parks is designed to document changes in snow and ice cover and vegetation productivity (NDVI). Monitoring questions identified by the SWAN include the following (Bennett et al. 2005):

- How are onset, duration, and extent of ice cover changing on large lakes in the SWAN region?
- How are timing, location, and duration of snow cover changing in SWAN parks?
- How are onset, duration and relative biomass of vegetation changing in SWAN parks?

The primary objectives for monitoring are outlined in this protocol:

1) Estimate variability and long-term trends in the timing and duration of lake ice formation (freeze-up) and thaw (break-up) in large lakes in the SWAN region.
2) Estimate variability and long-term trends in the timing and duration of snow cover in the SWAN region (establishment of snowpack; snowmelt).
3) Estimate variability and long-term trends in growing season NDVI in the SWAN region (start- and end-of-season dates; duration of growing season; maximum NDVI).

A fourth objective, the estimation of long-term trends in the timing and extent of sediment plumes in large freshwater lakes, will not be addressed at this time. The SWAN staff has examined available MODIS surface reflectance images for lake sediment plumes and has been unable to interpret ecologically meaningful information.

II. Sampling Design

The best technology currently available to address the SWAN's landscape processes monitoring objectives is MODIS. The calibration, spatial detail, and geolocation quality of MODIS data are significant improvements over its predecessor, AVHRR, which provided 4- to 6-band multispectral data at a resolution of 1.1 km. The combination of moderate spatial resolution, high temporal observations, and 100% coverage of the SWAN provides a framework of continuous and complete monitoring of the Network using the suite of MODIS products.

The MODIS satellite sensor processing system produces data at three spatial resolutions: 250m, 500m, and 1000m. The sensor collects 250m resolution data in the visible red and near infrared wavelengths, 500m data in the visible, near-infrared, and mid-infrared wavelengths and 1000m data from the visible through the thermal infrared wavelengths (Table 1). Because of its wide swath width (2330 km), the MODIS sensor collects near-global coverage every day, with multiple swaths (usually 2 or 3) over the SWAN.

Primary Use	Band	Bandwidth (μm)	Spatial Resolution (meters)
Land/Cloud/Aerosols Boundaries	1	620 - 670	250
	2	841 - 876	250
Land/Cloud/Aerosols Properties	3	459 - 479	500
	4	545 - 565	500
	5	1230 - 1250	500
	6	1628 - 1652	500
	7	2105 - 2155	500
Ocean Color/ Phytoplankton/ Biogeochemistry	8	405 - 420	1000
	9	438 - 448	1000
	10	483 - 493	1000
	11	526 - 536	1000
	12	546 - 556	1000
	13	662 - 672	1000
	14	673 - 683	1000
	15	743 - 753	1000
	16	862 - 877	1000
Atmospheric Water Vapor	17	890 - 920	1000
	18	931 - 941	1000
	19	915 - 965	1000
Surface/Cloud Temperature	20	3.660 - 3.840	1000
	21	3.929 - 3.989	1000
	22	3.929 - 3.989	1000
	23	4.020 - 4.080	1000

Atmospheric Temperature	24	4.433 - 4.498	1000
	25	4.482 - 4.549	1000
Cirrus Clouds Water Vapor	26	1.360 - 1.390	1000
	27	6.535 - 6.895	1000
	28	7.175 - 7.475	1000
Cloud Properties	29	8.400 - 8.700	1000
Ozone	30	9.580 - 9.880	1000
Surface/Cloud Temperature	31	10.780 - 11.280	1000
	32	11.770 - 12.270	1000
Cloud Top Altitude	33	13.185 - 13.485	1000
	34	13.485 - 13.785	1000
	35	13.785 - 14.085	1000
	36	14.085 - 14.385	1000

Table 1. Spatial and spectral characteristics of MODIS bands and their primary use.

The level of change that can be detected by the sampling being instituted for this protocol is a direct result of the temporal and spatial resolution of the various datasets. The spatial extent of any change must be resolved by the satellite. The spatial accuracy of MODIS data is generally said to be approximately 50m, therefore the minimum mapping unit of MODIS data is approximately 100m (accounting for possible 50m mis-registration in all four directions) plus the base resolution of the MODIS product. For example, the vegetation index data (250m resolution) has a minimum mapping unit of approximately 350m. This means that any change that takes place on the landscape must be resolvable at 350m spatial resolution. The change does not have to be 350m in extent to be measurable – a significant change (e.g., clearcuts) of less than 350m may impact the reflectance characteristics of the pixel sufficiently to influence the satellite measurements. Therefore, we may state that the level of change detectable by this sampling method must be resolvable at the spatial resolution of the various products. Similarly, we may state that the level of change in the temporal domain is resolvable according to the temporal resolution of the various products (Table 2).

Data Set	Spatial Resolution	Temporal Resolution
Calibrated Radiance	250m	daily
Snow Cover	500m	8-day and daily
Vegetation index (NDVI)	250m	16-day
Phenology measures		
Start of Growing Season	250m	Annual
End of Growing Season	250m	Annual
Duration of Growing Season	250m	Annual
Peak Growing Season	250m	Annual
Seasonally Integrated NDVI	250m	Annual

Table 2. Spatial and Temporal characteristics of SWAN MODIS data products.

MODIS data and data products are distributed by the EROS Land Processes Distributed Active Archive Center (LP DAAC), the Level 1 and Atmosphere Archive and Distribution System (LAADS), and by the National Snow and Ice Data Center (NSIDC) DAAC. The land processes MODIS data set includes 9 primary products (e.g., vegetation index (VI), surface reflectance, etc.) that are produced at a variety of spatial resolutions and temporal frequencies to yield over 40 land-related products.

The calibrated spectral radiance data are available through the LAADS, and require associated Geolocation files (also available from LAADS) for georeferencing the data sets (see SOP 4). Surface reflectance products were carefully evaluated for lake ice metrics and found to be unsuitable due to problems with patches of missing data, the aerosol corrections and between-path mosaicking anomalies.

The daily stitched products are further processed into temporal composites of 8 days or 16 days in order to reduce the effects of cloud cover and to reduce the data volume that would quickly become overwhelming with daily products. The data are processed into higher level products using a variety of algorithms that have been vetted and extensively reviewed by the scientific community. The MODIS products that are being supplied as baseline datasets to the SWAN and their spatial and temporal resolutions are given in Table 2. The snow data set is provided as both 8-day composites (corresponding to maximum snow extent during the 8-day period) and daily snow extents at 500m resolution; the vegetation index product is provided as 16-day composites and 250m spatial resolution.

The phenology products are derived from the 250m VI data. Any use of the general "VI" term is in reference to the MODIS product which contains both a NDVI and an Enhanced Vegetation Index (EVI) product. In reference to the standard "VI" product for this protocol, NDVI will be used. These phenology data are supplied as annual summaries (i.e., one summary value for each of the phenology metrics for each year). The products are produced in units appropriate for each metric they represent: i.e., the start and end of season metrics are expressed as Julian date, duration of growing season is expressed as number of days, and seasonally integrated NDVI is expressed in daily accumulated NDVI units (Table 2).

III. Data Acquisition, Processing and Analysis

In this portion of the narrative, the procedures for data acquisition, processing, and analysis will be discussed. Figure 1 provides a graphical representation of these procedures. The primary goal is to streamline the procedures for acquiring MODIS data from the LP DAAC, NSIDC and LAADS in addition to providing scripted methods for processing data into a usable format.

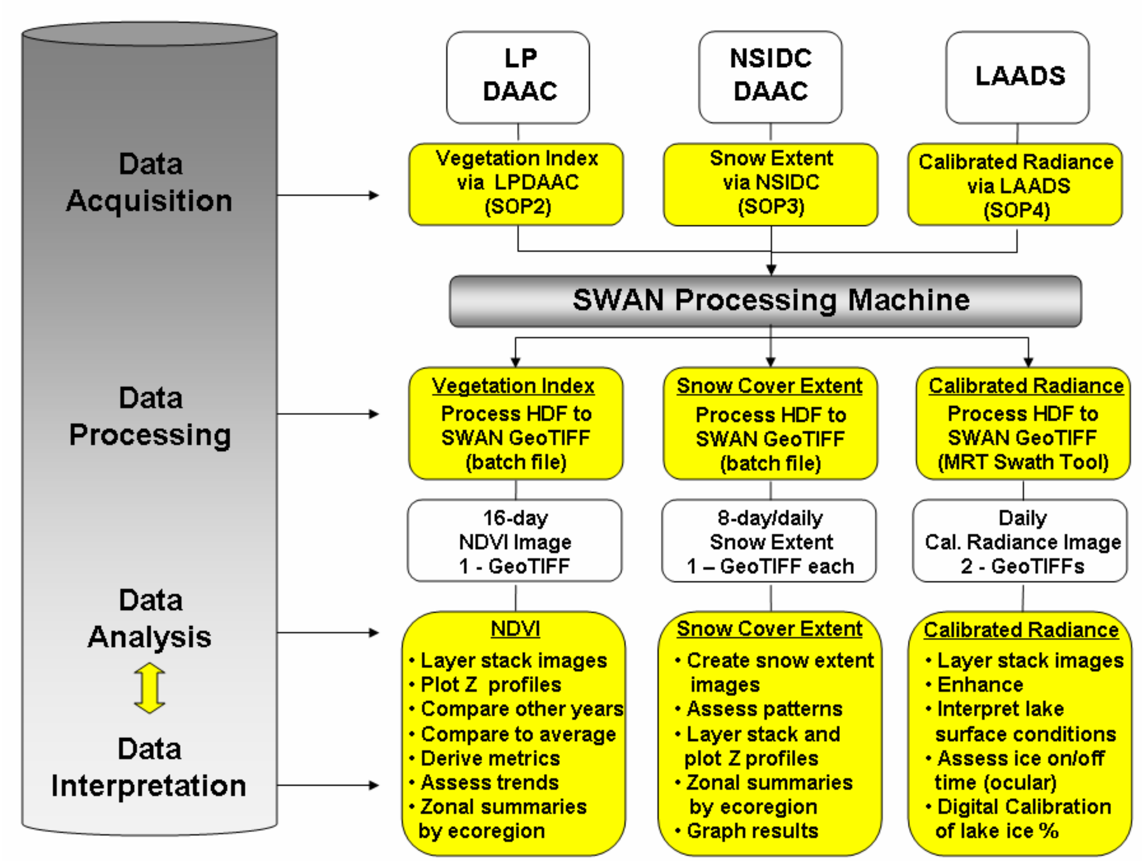


Figure 1. Flowchart of data acquisition, processing, analysis and interpretation for standard MODIS products. Yellow boxes represent procedures that are further described in the SOPs. The arrow between data analysis and data interpretation represents the analytical nature of these procedures.

The set of software that is required for the data processing and analysis consists of image processing, geographic information system, special-purpose free software provided by USGS, graphics software, and a spreadsheet or database (Table 3). In addition, a set of scripts are also required to run certain routines in the processing stages of the protocol. Table 3 lists the required software, the general application of the software and the SOP for which it is used.

Software	Application	SOP
ENVI	Image processing	2,3,4
IDL	Image analysis	2
ArcMap	Multiple data layer analysis	3
MODIS reprojection tool (MRT)	Image reprojection	2,3
MRT-Swath	Image reprojection	4
Excel	Data summary and reporting	2,3,4
ftp	Data transfer	2,3,4

Photoshop	Image enhancement	4
VI-processing script	Image processing	2
Snow (daily) processing script	Image processing	3
Snow (8-day) processing script	Image processing	3

Table 3. Software requirements for the Landscape Processes Protocol.

Data Acquisition

In addition to the baseline historical data sets that have been provided to the SWAN, three primary MODIS data sets are to be operationally acquired for monitoring of SWAN vital signs. These include the following:

- MODIS calibrated radiance from LAADS
- MODIS Normalized Difference Vegetation Index (NDVI) from LP DAAC
- MODIS snow cover extent from NSIDC DAAC

Both the LP DAAC and NSIDC DAAC have 'data pools,' or repositories of gridded MODIS data that are accessible via standard File Transfer Protocol (FTP). Calibrated radiance data for SWAN are selected and downloaded via FTP from the LAADS website at NASA Goddard.

The individual SOPs (SOP 2-4) provide further detail for each product type.

Data Processing

The files downloaded from each of the archive centers will appear as discrete tiles of data. The tile reference system is simply the row (vertical) and column (horizontal) number of the tile within the scheme. Coverage of the SWAN requires six tiles; h09v02, h09v03, h10v02, h10v03, h11v02, h11v03. The tile locations are shown in Figure 2.

Each data tile is provided in HDF-EOS format and is in the Sinusoidal projection. Since HDF-EOS is uncommon in many off-the-shelf image processing/geographic information system (GIS) packages and the Sinusoidal map projection severely distorts the SWAN, we have incorporated processing protocols that convert these tiled data to a single GeoTIFF image file in the Alaska Albers Equal Area Projection (Appendix 1).

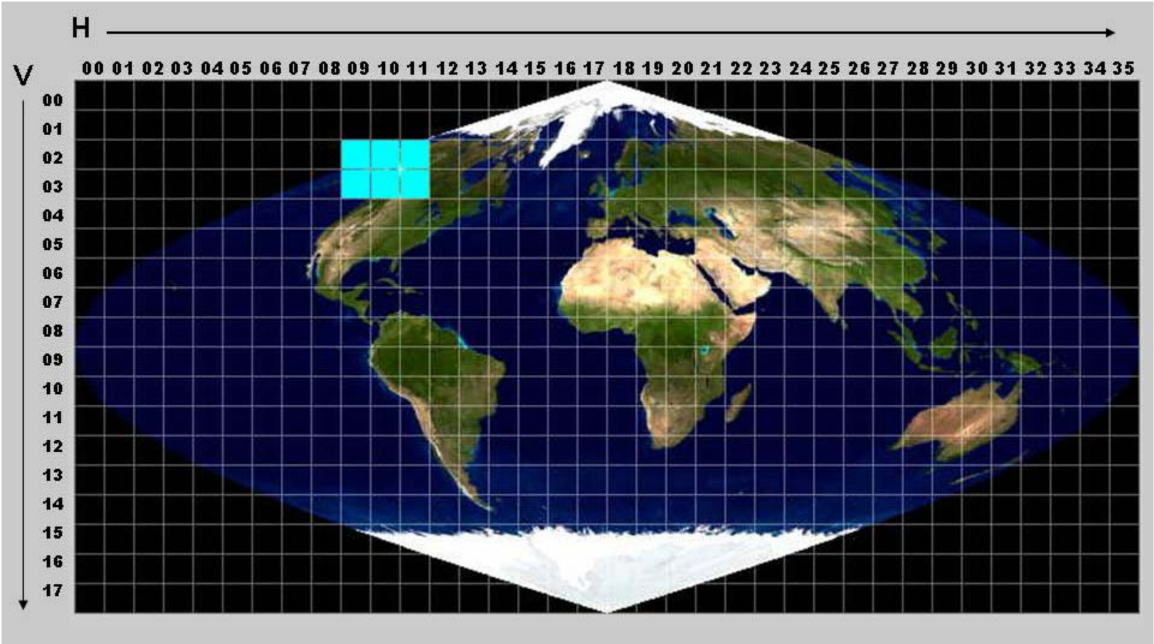


Figure 2. Horizontal/Vertical tile locations for coverage of the SWAN.

In the case of the NDVI and snow cover data, once the data tiles have been downloaded from the appropriate DAAC location, NPS personnel run a simple executable (List_HDF.exe) to create a text file containing the full set of HDF tile names for each composite period. The output text files are named using the four-digit year and three-digit Julian date corresponding to the first day of the composite period (i.e. 2006001.txt, 2006009.txt, etc.). This HDF-EOS file list is used as an input to the data processing scripts.

The processing scripts utilize the MODIS Reprojection Tool (MRT), which was developed by the LP DAAC to address issues related to data format and projection. The MRT can mosaic, subset, reproject, and reformat the raw HDF-EOS tiles in a single process. It can be executed using either a graphical user interface (GUI) or directly from the command line.

For the SWAN, batch file scripts have been developed that will execute the mosaic and resample commands within the MRT command line structure. These commands require that two input files exist; a list of raw MODIS tiles for processing and a parameter file that describes the spatial subset, projection, and output format. Parameter files for each composite period through 2008 have been provided for each of the MODIS products.

When data have been downloaded from the respective data pools, NPS personnel need only run the list executable described above to create the input text file and then execute the product batch file to create consistently processed time-series collections of MODIS NDVI and snow cover data sets.

The daily calibrated radiance data will utilize the MRT Swath tool for processing the MOD02 calibrated radiance HDFs and their corresponding MOD03 geolocation files into two single band files. The methods for processing these data using the MRT Swath GUI are further described in SOP 4 of this protocol.

Data Analysis

While there are proven methods for monitoring landscape processes using vegetation index data, the analysis of other data sets for SWAN vital sign monitoring will be largely exploratory in the initial phase of protocol implementation. Hence, we provide detail of the methods used for time-series analysis of the vegetation index data (SOP2) and present suggested analysis techniques using the calibrated radiance and snow cover data sets.

Calibrated Radiance. Analysis of calibrated radiance data will largely be through manual interpretation of natural color and/or color infrared composited imagery for the assessment of metrics such as lake ice formation and break-up and duration of freeze-up and break-up seasons, (SOP 4). Periodic digital calibration will standardize the interpreters to the images and each other.

Normalized Difference Vegetation Index. The MODIS vegetation index data that have been collected for the SWAN provide a unique opportunity to study changes in vegetation phenology over time. A variety of methods for using time-series NDVI data have been developed to extract critical phenology metrics such as the start of the growing season (SOS), time of peak greenness, end of growing season (EOS), and duration of growing season (DOS). The derivation of such parameters through time allows for the comparison of trends in the timing and magnitude of such events. The SWAN will use methods identified by Reed et al. (2003) to calculate annual summaries of phenology metrics. Analysis techniques for phenology metrics and annual reporting of vegetation trends are further described in SOP 2.

Snow Cover. The MODIS snow cover product will be used primarily as a measure of the on/off period throughout the Network. This product does not provide a measure of snow depth, but rather a maximum extent of snow covered area within an 8-day composite period or on a daily basis. These data have been used successfully to monitor snow cover accumulation and depletion across large areas. For the SWAN, it is useful to quantify the presence of snow in terms of a zone (ecoregion) which can be compared from year to year. We will use a simple ecoregion analysis, conducted within a GIS framework, to provide percent cover for every 8-day period (SOP 3). Where more temporal detail is needed, daily snow cover data can be used.

IV. Data Management

Data management will be a critical component of this protocol as both data volume and data diversity will be significant issues. Data management will be required at two levels; operational and archival. Operational data management includes the routine acquisition and processing of MODIS data and handling the subsequent data analysis. Archival data management includes handling the databases that will serve as baselines for vital sign monitoring and the long-term data sets that are created during analysis procedures.

Operational Data Management.

The priority operational data management is to organize the pertinent data products for transfer to the archival data management. Secondary concerns will include handling the raw data products from the LP DAAC, NSIDC DAAC, and LAADS, efficient, yet conservative management of temporary files, production and storage of analysis files, and deletion of temporary files. The operational data management will be the responsibility of the research ecologists and will include ongoing communication and revision to the process with the data management specialist.

The operational data management will include the following steps:

1) downloading of data from LP DAAC, NSIDC DAAC, and LAADS
2) implementing the standard data processing scripts
3) implementing non-standard data processing (as needed)
4) conducting data analysis
5) transferring the archival data to data manager

As the operational data management will be conducted in a PC environment, a suggested organizational structure for operational data management follows. It is assumed that the primary disk drive will be D:\ in this example:

D:\SWAN\MODIS_CalRad\yyyy
D:\SWAN\MODIS_VI_16day\yyyy
D:\SWAN\MODIS_Phenology\yyyy
D:\SWAN\MODIS_SNOW_8day\yyyy
D:\SWAN\MODIS_SNOW_daily\yyyy

where yyyy is the year the data are collected. Each of these file folders is where the primary data processing will take place. The standard processing will take place approximately every month. Under normal conditions, the set of processes should be completed in two to three days.

Because a number of ancillary files are necessary for the routine processing of the snow and vegetation index products, files with the following file extensions will be present within each of the file folders listed above:

*.txt	text documents containing file names for input to data processing scripts
*.prm	parameter files that are necessary for reprojecting files
*.tif	output image files that are to be placed into the data management archive

These files should be maintained in the operational system, but only the *.tif files should be delivered to archival data management.

As mentioned earlier, in addition to the routine data processing, the research ecologists will be conducting exploratory analysis on a regular basis that should not involve data that are housed in the file folders listed above. A conservative data management structure that does not endanger any of the routinely processed files is recommended. Therefore for the exploratory data analysis, the following parallel file structure is suggested:

D:\SWAN\Analysis\ MODIS_CalRad\yyyy
D:\SWAN\Analysis\MODIS_VI_16day\yyyy
D:\SWAN\Analysis\MODIS_Phenology\yyyy
D:\SWAN\AnalysisMODIS_SNOW_8day\yyyy
D:\SWAN\Analysis\MODIS_SNOW_daily\yyyy

Archival Data Management.

Archival data management will be required on all the baseline (standard) data sets and those data sets resulting from analysis procedures that merit promotion from operational to archival status. A data set consisting of processed MODIS products has been provided to serve as the original baseline data dating from February, 2000. The existing data set and projected data volumes are approximately as shown below in Table 4:

Existing Data Set (2000-present)	**Size (Gb)**
Calibrated Radiance	88.0
Vegetation Index (NDVI)	7.8
Phenology metrics	0.6
Snow Cover 8-day & Daily	7.5
Total	97.0

Projected Annual Increase	**Size (Gb)**
Calibrated Radiance	13.0
Vegetation Index (NDVI)	0.9
Phenology metrics	0.1
Snow Cover 8-day & Daily	1.1
Supplemental satellite data, inc ASTER	5.0
Total	≥20.0

Table 4. Existing and projected data volumes for SWAN MODIS and ASTER products.

There will be an estimated increase in data volume of 15-20 gigabytes per year. In addition to the basic data sets, there will be supplemental satellite data collected for augmenting this information. The supplemental data could include high resolution imagery (e.g., ASTER) that could be helpful in interpreting details that may not be discernible on the MODIS imagery. Additional data sets will also result from data analysis applications. These supplementary data sets may result in an additional 5 gigabytes per year.

The completed data products will be stored long-term as read-only files on the Alaska Regional central data file server. These data will be jointly managed by the SWAN data manager and the Alaska Regional Office (AKRO) GIS staff and will adhere to the AKRO GIS requirements. These data will be available to Alaska NPS staff by using the ArcGIS Theme Manager or by direct access to the data file server. The National Park Service does not have the capability to post data sets of this size on the Internet at this time. Public access to these files will be by special request. Metadata for available products will be posted on the NR-GIS Clearinghouse.

Draft or interim data will be stored short-term on the SWAN Team data file server and will be read-write accessible to SWAN staff. These data include files that are originally downloaded or temporary files used to generate the final data products. These should be removed when the final data products are completed.

Backup procedures for these data sets should follow the National Park Service's normal procedures. Backups are managed by the Alaska Regional Information Technology staff as described in the SWAN Data Management Plan, Section 11.5.

Documentation

One metadata record per image type will be produced and will meet the Federal Geographic Data Committee (FGDC) Content Standards for Digital Geospatial Metadata (CSDGM). The metadata records should cite this protocol in the 'Larger Work Citation' field. An example metadata file is shown in Appendix 2.

Quality Assurance/Quality Control and Validation

Quality assurance and control is a major element of the original MODIS product development (before the Landscape Processes Protocol is implemented). For a summary of the types of processing QA/QC that have been implemented, see an overview of the Land Data Operational Product Evaluation (http://landweb.nascom.nasa.gov/cgi-bin/QA_WWW/newPage.cgi). Similarly, many of the standard MODIS products have undergone validation experiments. The MODIS Land Processes Validation web site summarizes many of these efforts (http://landval.gsfc.nasa.gov/index.php).

V. Analysis and Reporting

This portion of the narrative includes descriptions of analysis techniques and products for the lake ice, snow cover and for the NDVI derived phenology metrics. It also provides examples of products that may be useful in annual reporting of vital signs monitoring.

Lake Ice

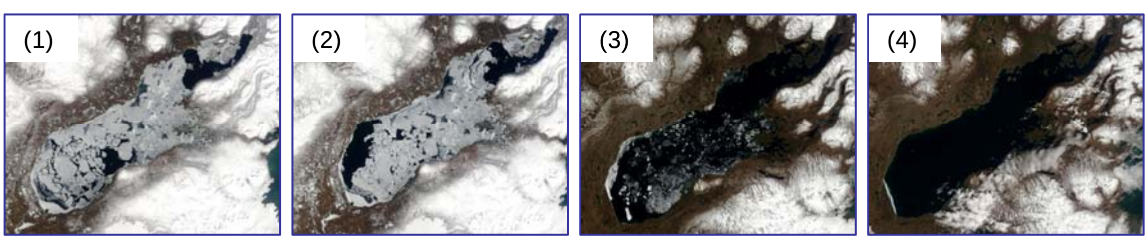
SWAN is located in an extremely dynamic region of Alaska, where maritime and continental climate regimes meet. Climatic patterns are exacerbated by topographic relief and peninsulas that extend into the North Pacific Ocean and Bering Sea. Ice metrics on large lakes and lake complexes are indicators of the cumulative thermal regime across SWAN (Jeffries et al, 2005). A warming climatic trend should lead to shorter ice-bound seasons on lakes, while overall colder climate will lead to longer ice seasons. These trends will likely vary spatially across SWAN and be reflected in different lakes. The objective of this protocol is to determine the natural variability in ice season in SWAN and detect long term trends in ice season duration and freeze-up/break-up dates.

Lake ice metrics are interpreted from daily MODIS Calibrated Radiance (MOD02) images. Lake ice metrics are break-up date, freeze-up date and duration of ice season, break-up season and freeze-up season. Seventeen lakes and lake systems are selected for interpretation of ice cover. Each daily image is examined and the ice cover estimated and recorded. Calibrated radiance data are available early in the processing stream, so have no atmospheric corrections. As such, they can not be automatically compared between dates. Manual interpretation of calibrated images is used to derive the ice season metrics. Digital calibration is used to standardize ocular estimates through time and between interpreters.

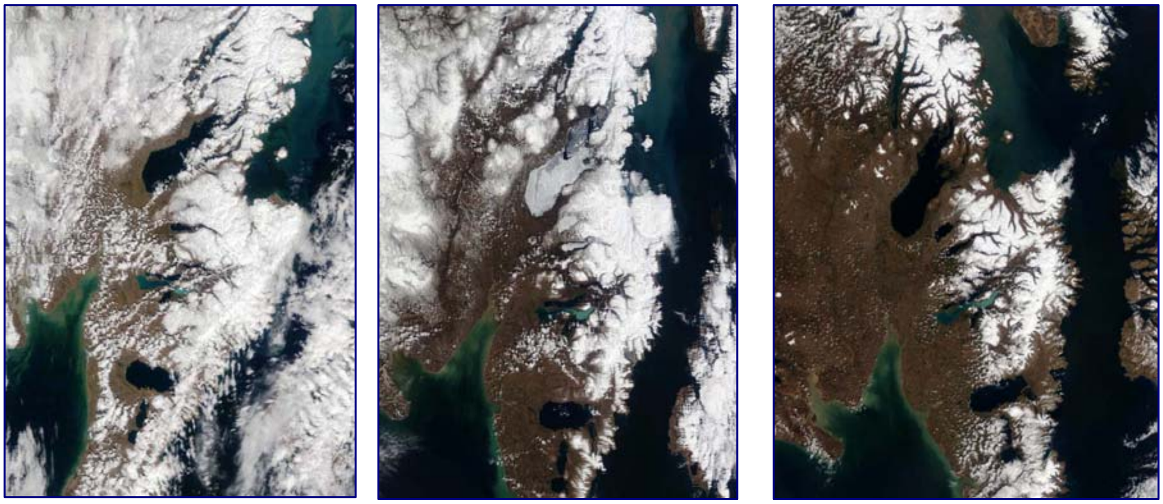
Freeze-up date is when ice cover is >90%. Break-up date is when ice cover is <10%. Ice season is the number of days between freeze-up and break-up (Jeffries et al, in press). Number of days for break-up season and freeze-up seasons are also recorded. Annual reporting will consist of a chronology of lake ice events and processes (dates of onset, freeze-up and duration).

The long term record will be analyzed to determine if there are trends in dates and duration of ice events. Preliminary interpretations of the MODIS data suggest that landscape-scale phenomena across the SWAN are complex. For example, large lakes vary in their timing and rate of freezing and often do not have single freeze-up or break-up events. Some lakes freeze early in the season and remain frozen until late in the spring, when they break-up very rapidly (Fig. 3). For these lakes, break-up dates have been surprisingly consistent across years (2001-2006). Other lakes are much more variable, and in some years do not freeze at all.

Below (L-R): MODIS time series of breakup of lake ice on Lake Iliamna, April 15 - May 10, 2005. (1) April 15; (2) April 17; (3) May 8; (4) May 10. Rapidfire images.



Below (L – R): MODIS time series of mid May 2001-2003 for the Alaska Peninsula from Lake Clark south to Becharof. Rapidfire images.



May 17, 2001 May 12, 2002 May 16, 2003

Figure 3. Timing of lake ice breakup for Lake Iliamna and interannual variation of ice cover for Lake Clark.

Vegetation Index

A major utility of the vegetation index time series is the ability to measure seasonal vegetation dynamics (Fig. 4). Phenology metrics of start of season (SOS), end of season (EOS), duration of the season, time of maximum NDVI, value at maximum NDVI, and total growing season NDVI were provided to the SWAN for the years 2000-2005. As part of the operational processing stream, the SWAN will acquire 16-day composites of vegetation index data throughout the year. Once a full year has been acquired, the new data will be added to the vegetation time series and phenology metrics will be derived for the additional year.

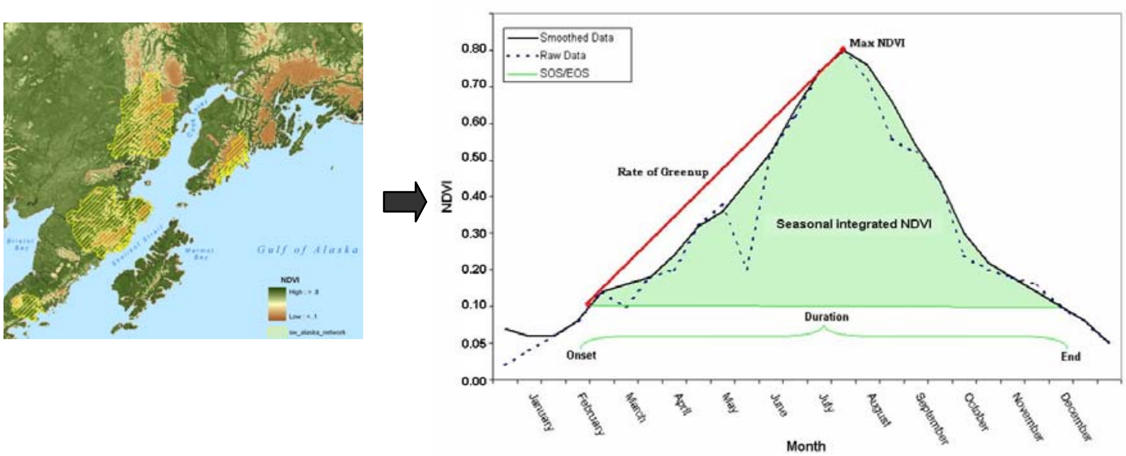


Figure 4. NDVI image (left) and the profile for a single year (right), illustrating derived phenology metrics.

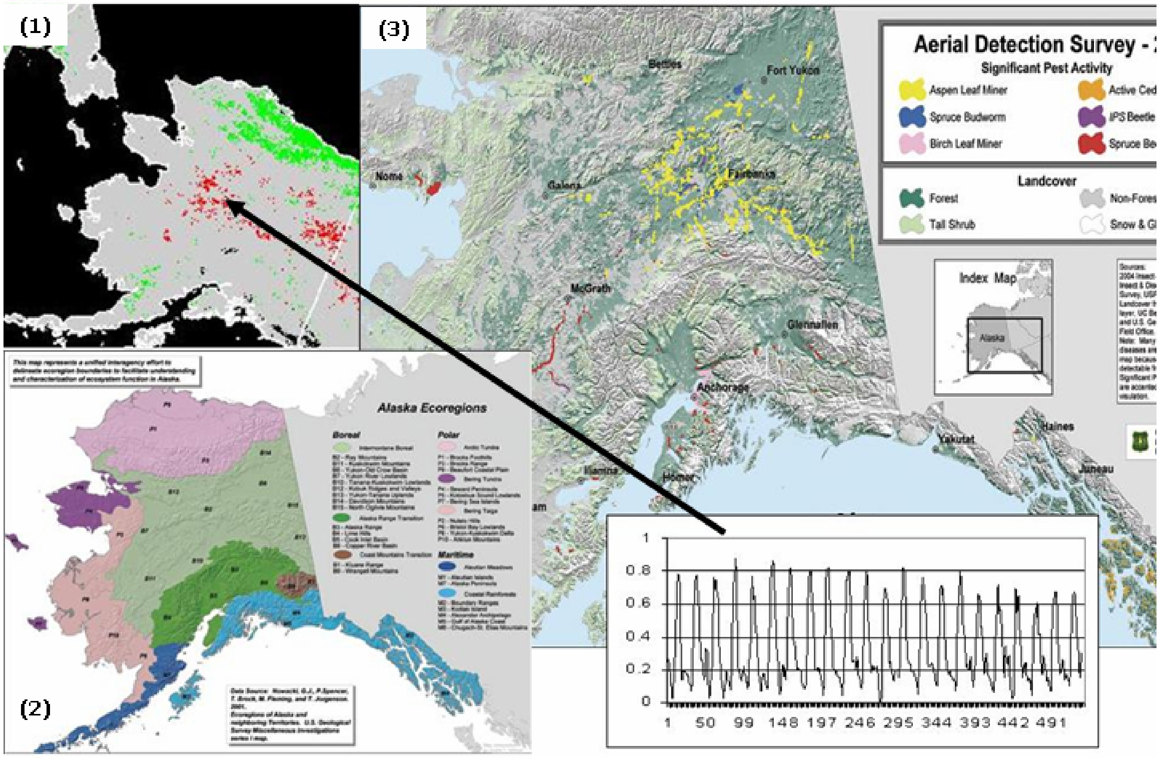


Figure 5. Trend analysis of the AVHRR time series of North America shows both increasing (green) and decreasing (red) trends in growing season NDVI in Alaska during the years 1982 – 2003 (1). Decreasing productivity was localized to a single boreal ecoregion (2) and the areas of decrease coincide with defoliation or forest mortality (3).

The results of the phenology analysis will be evaluated for each of the primary vegetation communities in cooperation with network ecologists. As the length of the temporal profiles of vegetation dynamics increase, they provide the opportunity to analyze trends in vegetation phenology patterns over time. Figure 5 shows an example of trends in growing season greenness for Alaska using coarse spatial resolution high temporal resolution data acquired from AVHRR. The areas in red indicate a trend toward reduced growing season greenness, while the areas in green are indicative of increasing greenness trends during the same period (1982- 2003).

The trend analysis technique applies a best-fit line to the phenology metric data and performs a simple t-test to determine if the slope of the line is significantly different from 0. Slopes that are significantly greater than 0 indicate an increasing trend, while slopes significantly less than 0 represent a decreasing trend. While this type of analysis is typically used for looking at medium- to long-term trends in vegetation dynamics (> 10 years), annual reporting will be limited to the mapping of annual phenology metrics (Fig. 6), and/or the plotting of time series for SOS, EOS, etc., for visual comparison with previous years (SOP 2).

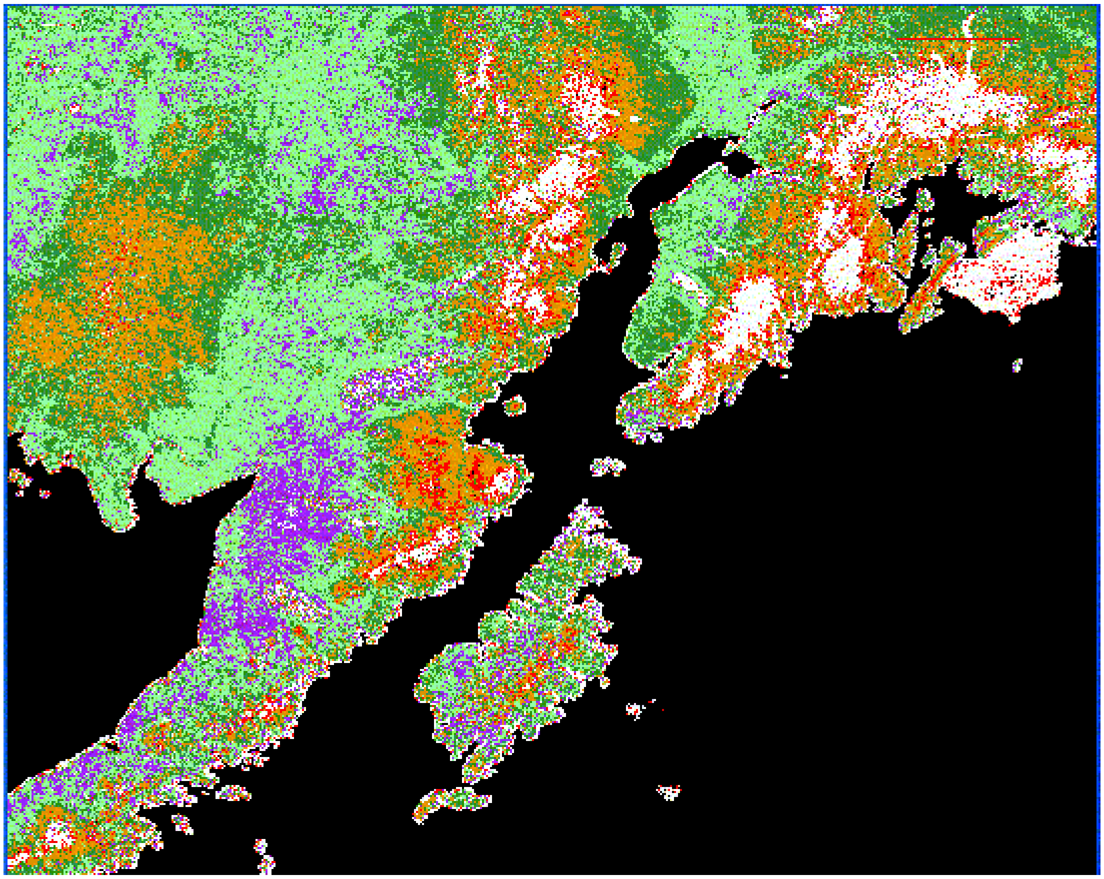


Figure 6. Time of start of season image, 2004; White = no growing season, purple = SOS in March, light green = SOS from April 1-15, dark green = SOS from April 16-30, orange = SOS in May, and red = SOS in June.

Snow Cover

MODIS provides a standard measure for monitoring the extent of snow covered area within the SWAN via both daily and 8-day composite snow products. The snow cover products are created by applying a normalized difference snow index (NDSI) algorithm to the surface reflectance. The result is a classified image that allows the analyst to identify incremental changes in snow cover throughout the region as well as quantify the snow covered area within a given zone.

The snow cover data is available approximately 3 – 4 days after the close of the composite period, allowing timely measures of snow cover over large areas. Visual analysis of snow patterns, such as those seen in Figure 7, can be compared with previous years to identify anomalous snow conditions. As with the NDVI product, ancillary data (e.g., from SWAN weather stations) has the potential to greatly inform monitoring efforts with MODIS.

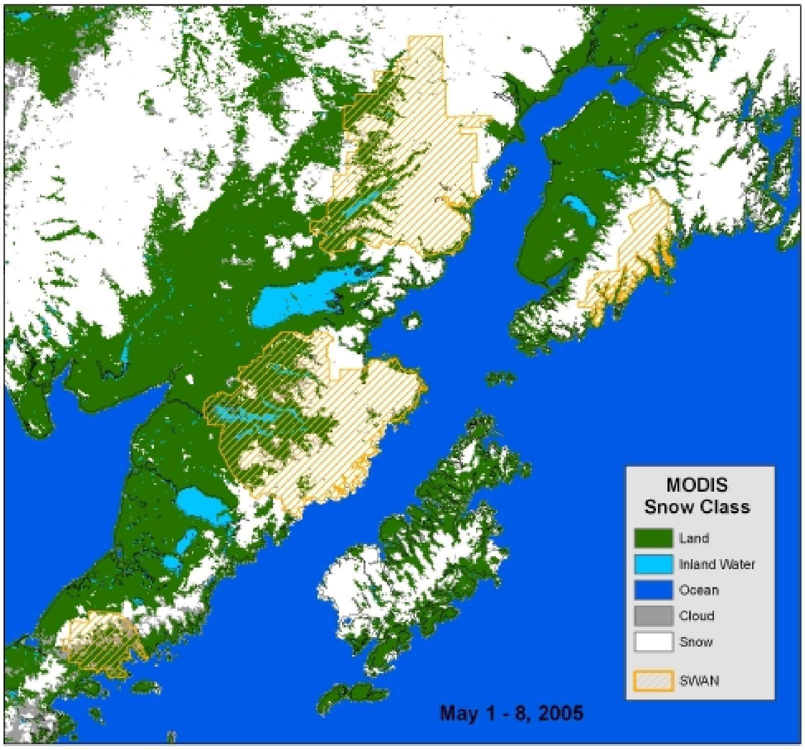


Figure 7. Eight-day MODIS snow cover extent image for 1-8 May 2005. The major classification categories and the SWAN park boundaries are mapped.

A more quantitative measure of the snow cover extent can be derived using a zonal coverage for time series analysis of snow covered area. The defined zone could represent an ecoregion, drainage basin, park or some other delineation for which snow covered area would be a meaningful metric. Here, we will summarize snow duration and extent by ecoregion (Nowacki et al, 2002) using the 8-day snow cover composites. Standard snow cover accumulation/depletion curves relate the percent of a basin or zone that is covered by snow to elapsed time during both the snow accumulation and snow melt seasons. Such curves help provide an indication of the temporal and spatial extent of seasonal snow pack and its potential impact on water resources. A steep decrease in snow-covered area can be indicative of either shallow snow pack or high melt rates. On the other hand, a slow decrease results from either a deep snow cover or slow melt rates most likely due to low temperatures. Plotting snow cover versus growing degree days can help reduce this ambiguity, however this would require additional climate data inputs, such as those from the new SWAN weather stations. Curves measuring the maximum extent of snow cover as a function of time without regard to air temperature can still be very useful in the assessment of snow covered area.

The time series plot shown in Figure 8 illustrates the comparison of 2004-05 snow cover with the previous year as well as a short term average condition calculated using 4 years of MODIS snow data. The plot illustrates that while the onset of the snow season in this area was later than the comparison periods, the duration of cover was longer, the spatial extent of cover was greater, and the time of depletion was later, indicating an abundant supply of melt water in the spring.

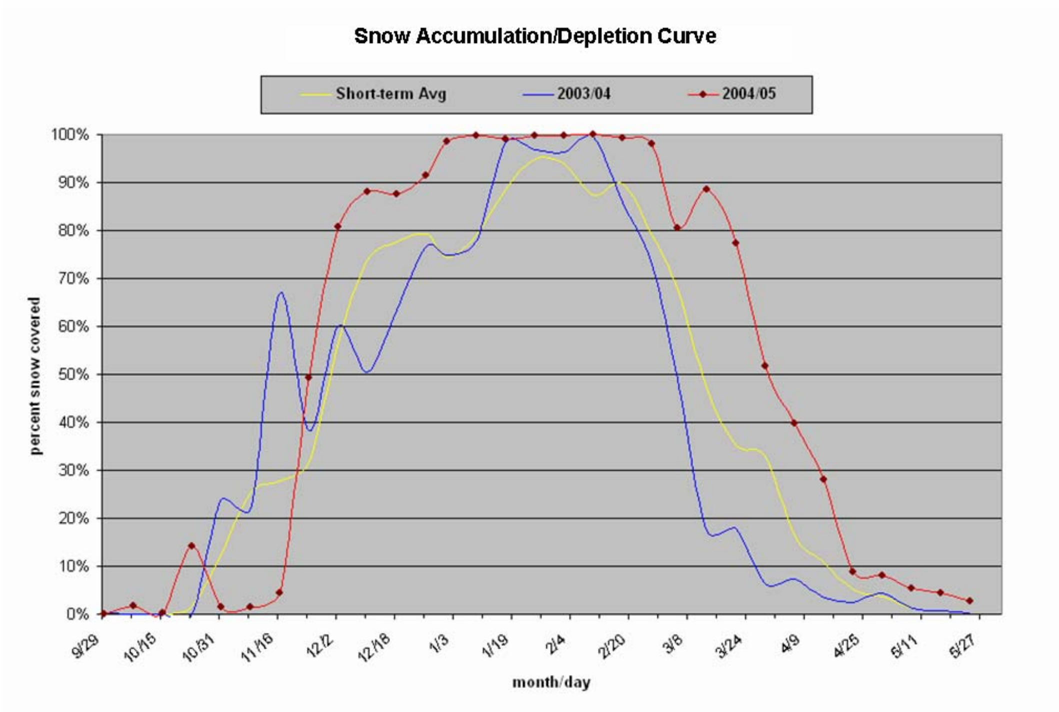


Figure 8. Example of a snow accumulation/depletion summary.

As a supplement to the 8-day composite data, daily snow cover imagery can be used to more precisely measure the timing of snow cover events given cloud free acquisitions. Another use of the daily images for analysis of annual snow cover conditions will be to create daily time series of snow cover for each year and assess temporal patterns using the z-profile plotting functions in ENVI. The procedures and applications of this type of analysis are further described in SOP 3.

Reporting

Communication of monitoring results will occur through annual summary reports and informal meetings with park managers, and through multi-year synthesis reports. Annual reporting will consist of a chronology of lake ice (dates of onset, break-up, and duration), snow cover (dates of first measurable snowfall, establishment of permanent snowpack, beginning of melt, end of melt) and productivity metrics (dates for start and end of season, maximum NDVI, integrated NDVI) for selected study areas. In addition, spatial variation in these metrics will be recorded (e.g., extent of snow cover) and a range of values provided for each metric across the Network (e.g., variation in date of lake ice onset across the Network). Any observed anomalies, or any conditions that may confound interpretation of the data, will be recorded. Changes to the protocol will likewise be documented. Synthesis reports could include results of time-series analyses, graphical representation of selected metrics (e.g., Fig. 6), and/or mapped regions of change (e.g., areas experiencing a shorter or longer growing season (Fig. 5), or earlier or later onset of lake ice). Table 5 outlines metrics that will be included in annual and multi-year reports.

Ancillary data used during data analysis and interpretation and verification may include SWAN climate/temperature records (e.g, Harding Icefield Weather Station), lake ice records (e.g., X:\Libraries\Database_Water\SWAN\AK_Lake_Ice_Monitor_History), historic accounts and journals, and informal reports from park pilots and backcountry rangers.

Guidelines for formatting annual summary and 10-year synthesis reports are as follows:

http://www.nature.nps.gov/im/units/swan/Libraries/Data_Management/DataManageGuidelines/SWAN_ReportAnnualFinalSpec_0412.pdf

Vital sign	**Metrics**
Lake ice	For a given lake: • date of initial freeze-up • date of final freeze-up - continuous ice • date of initial break-up • end of break-up – ice-free • duration of break-up season • duration of ice season • duration of freeze-up season • duration of ice-free season • range of break-up and freeze-up dates, seasonal durations across SWAN region
Snow cover	For a given study area or ecoregion: • date of first measurable snow cover • date of snowpack establishment – onset • date of first measurable snow melt • end of snow melt – snow-free Across SWAN: • maximum extent of snow cover (mapped) • range of snow onset and melt dates across study areas
Productivity	For a given study area or ecoregion: • date of first measurable NDVI - onset • date of decline in NDVI – senescence • maximum NDVI • integrated NDVI • duration of growing season Across SWAN: • range of onset and senescence dates across study areas

Table 5. Reporting summary for landscape processes vital signs.

VI. Personnel Requirements and Training

The implementation of this protocol (Table 6) requires a diverse skill set including expertise in remote sensing, geographic information systems, data management, and landscape ecology (Table 7). Although the levels of expertise required for the continuity of the protocol vary, a high level of competence is necessary to build the protocol and standard operating procedures and maintain them through the initial stages of the project. After the procedures have been successfully operating, the level of expertise required in remote sensing, geographic information systems, and data management will be reduced. However, an ongoing high level of expertise by ecologists will be required throughout the duration of this protocol, as data interpretation cannot be completely automated.

Task	Personnel
Data acquisition: -Routine downloads -Automated preprocessing	Data Technician
Data processing: -Custom processing, enhancements	Ecologist or Remote Sensing Specialist
Data analysis and interpretation: -Manual interpretation of metrics -Manual or automated determination of metrics -Spatial analyses -Trend analyses -Data summaries	Ecologist, with assistance from GIS Specialists, Remote Sensing Specialist, and Statistician
Reporting	Ecologist
Data management: -Copy new files to Central Data Server -Manage data formats, directory structure, archiving -Maintain consistent data characteristics and software compatibility with other SWAN data sets	Data Manager, GIS Specialist, and Ecologist
Backups	All Users (local) and AKRO IT staff (archives)
Minor protocol revisions and documentation	Remote Sensing Specialist and/or Ecologist
Development of alternative processing scenarios: major protocol revisions	USGS-EROS staff or similar expertise

Table 6. Work flow and responsibilities for monitoring of landscape processes.

Data downloads and processing will need to be accomplished at least monthly before the data are deleted from the LP DAAC and LAADS data pools. These tasks will require a minimum of 3-4 days/month. Interpretation of the images will be conducted annually.

The analysis, interpretation and reporting phases of these SOPs will require approximately 0.5 FTE by the ecologists and remote sensing/GIS specialists combined.

Personnel	Qualifications/Experience
Data Manager	• Experience with data stewardship and developing applications for data analysis
Remote Sensing Analyst	• Extensive experience with MODIS products and specialized software (MODExtract, MODIS Reprojection Tool (MRT), MODIS quality assurance tool - Land Data Operational Product Evaluation (LDOPE)) • Experience with image processing, including ENVI software • Experience in regional-scale remote sensing applications • Experience in deriving phenological metrics • Experience with time-series analysis
GIS Specialist/Analyst	• Experience in assembling data sets with disparate characteristics (e.g., raster/vector, map projections, data formats) and harmonizing them
Ecologist/Analyst	• Familiarity with SWAN landscapes and landscape processes, including field experience • Experience in manual interpretation of satellite imagery and derived products • Ability to synthesize information from multiple data sets to develop summary reports of short- and long-term variation in phenological metrics
Data Technician	• Experience with GIS and data management

Table 7. Personnel qualifications for monitoring of landscape processes.

Training procedures.

All personnel involved in this protocol should receive training in ArcGIS and ENVI software on a one to two year schedule.

VII. Operational Requirements

Workload /Acquisition Schedule

Because these data are ingested and stored at their respective archive centers, the timing of data collection is not as crucial as in field based protocols. Nevertheless, maintenance of an up-to-date archive of SWAN data sets will require adherence to a regular download and processing schedule.

Calibrated Radiance data are continuously maintained and available from the LAADS web site. Vegetation index data remain staged on the LP DAAC data pool for up to one year. On occasion, these data are removed from the data pool prematurely, but always remain available via the EOS Data Gateway (EDG). In the case of the snow cover data, the NSIDC DAAC maintains a complete archive of 8-day and daily data in their data pool. As with data via the LP DAAC, if these would be removed from the data pool, they are always accessible through the EDG.

Table 8 shows the composite period length and the number of days, after the close of the composite period, when products are typically available for download. Downloading will take place at least monthly - well before the data are deleted from the data pools. If analysts miss several periods and the data are no longer available in the data pool, they can be retrieved from the EDC Archive or LAADS using the procedures outlined in Appendix 3 and SOP 4.

Product	Composite Length	Availability (# of days)	Source
Calibrated Radiance	daily	1	LAADS
Vegetation Index	16-day	5-7	LP DAAC
Snow Cover Extent	8-day	3-4	NSIDC DAAC
Snow Cover Extent	daily	2-3	NSIDC DAAC

Table 8. Approximate data availability schedule for each MODIS product.

Hardware Capability

The hardware requirements for processing, storage, and analysis of MODIS satellite imagery include a personal computer with a minimum of 2.0 GHZ processor and 1.0 GB or greater of memory. These are minimum requirements; to achieve maximum performance in processing and manipulation of imagery, more powerful processors and memory are necessary. A minimum hard drive capacity of 200 GB is recommended for MODIS processing and storage.

Software

The software requirements for utilizing MODIS data sets can be categorized into two groups. Software tools necessary for the acquisition and processing of raw MODIS tiles and swaths, and software packages that allow the processed imagery to be viewed and analyzed with other spatial data.

The software tools for acquisition and processing of MODIS tiles and swaths include the following:

- MODIS Reprojection Tool (MRT)
- MODIS SWATH Reprojection Tool (MRT-Swath)
- Land Data Operational Product Evaluation (LDOPE)

All of these are freeware tools that can be downloaded from the LPDAAC website (http://edcdaac.usgs.gov/datatools.asp).

The image processing and GIS software that is used for display and analysis of processed imagery will be left to the discretion of the NPS. However, we recommend RSI's ENVI image processing software and ESRI's ArcGIS. Adobe Photoshop is also an invaluable tool for rapid image viewing and feature enhancement.

Software installation instructions (MRT, MRT-Swath, and LDOPE) are found in SOP 1.

VIII. Procedures for Revising Protocol

The steps for changing the protocol (either the protocol narrative or the SOPs) are outlined in SOP 6. Each SOP contains a revision history log that should be filled out when a SOP is revised. The new version of the SOP and/or protocol narrative should then be archived in the SWAN protocol library under the appropriate folder.

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